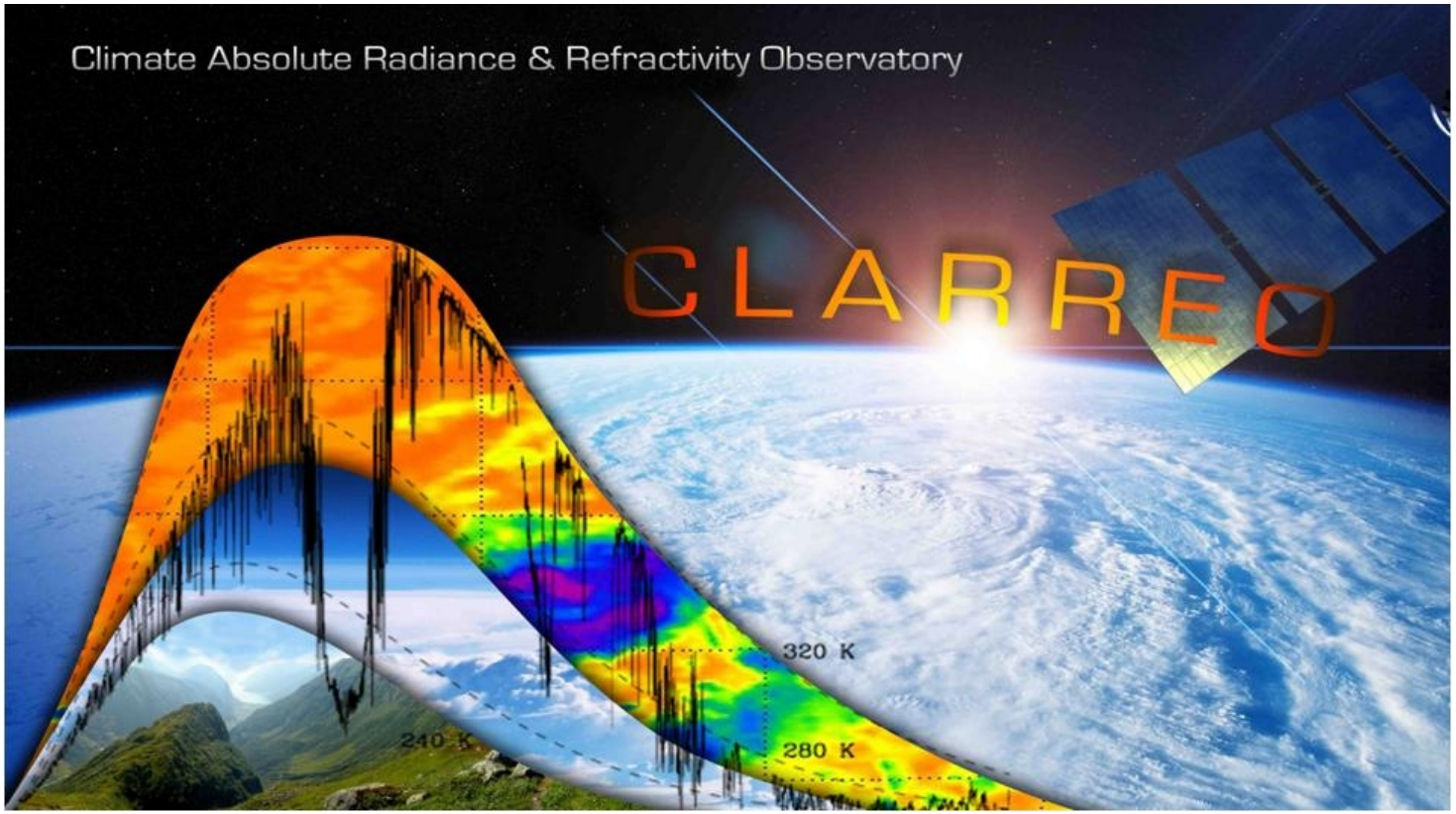


CLARREO Pathfinder – SDT Overview

Early Discussions

Background

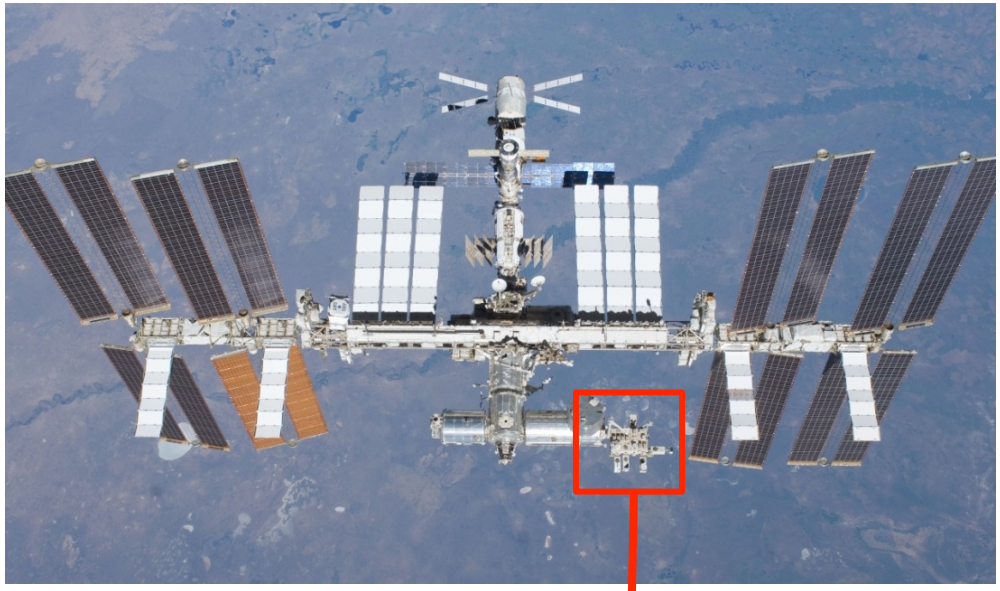
- History:
  - November 2010 CLARREO passed MCR with no major RFAs; recommended to proceed to Phase A
  - Budget reductions in Feb. 2011 placed CLARREO back into pre-formulation.
  - 2013 - CLARREO developed an ISS concept. Presented to HQ.
  - 2014 - Steve Volz asked the SEWG to put out a call for Technology Demonstration ideas that could go the ISS.
    - LASP, UW, GSFC submitted concepts for the RS and IR
    - Follow-up conversations with Volz requested additional information with budget phasing information
  - 2014 – CLARREO develops low cost free-flyer mission concepts
  - 2015 – February. President's budget includes a CLARREO Pathfinder line; fly RS and IR on ISS with a 2019 launch.
- Recent Actions:
  - Planning, Programming, Budgeting, and Execution (PPBE) response due to NASA HQ on April 15th, 2015 (Tax Day).
  - Purpose: Formulate the scope of work, submit ROM budgets, demonstrate feasibility

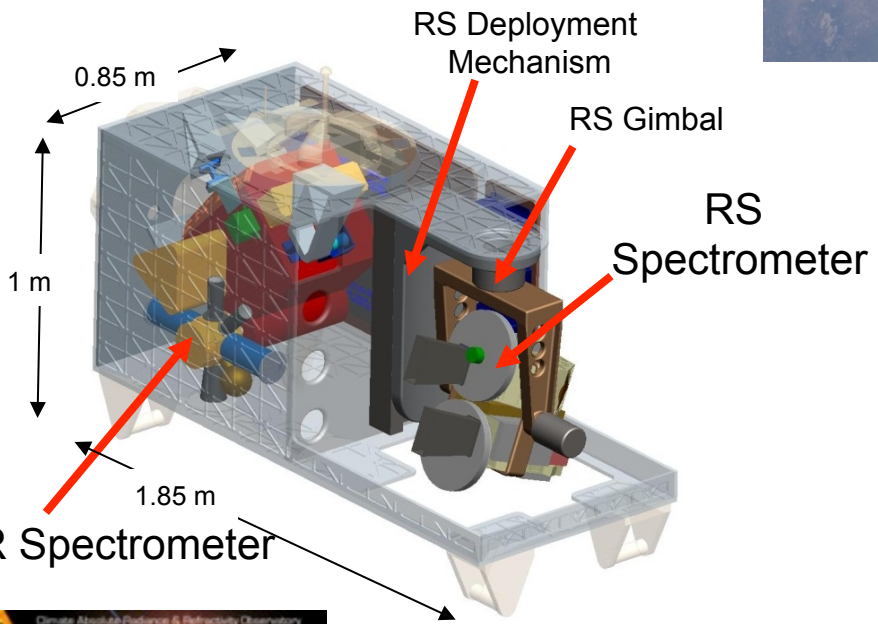
ISS Implementation Options (2013)

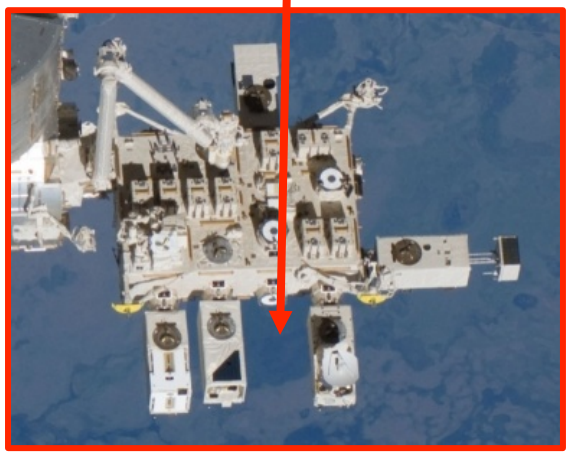
Mission Concept Readily Accommodated on the ISS

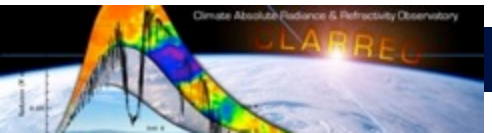
CLARREO ISS Concept Design 2013

- Selected the Japanese Experiment Module Exposed Facility (JEM-EF) for this study
  - Other sites viable, but ram-side of JEM-EF is optimal for maximizing viewing opportunities
- Box occupying one experiment location









CLARREO-ISS Accommodation Compliance Matrix

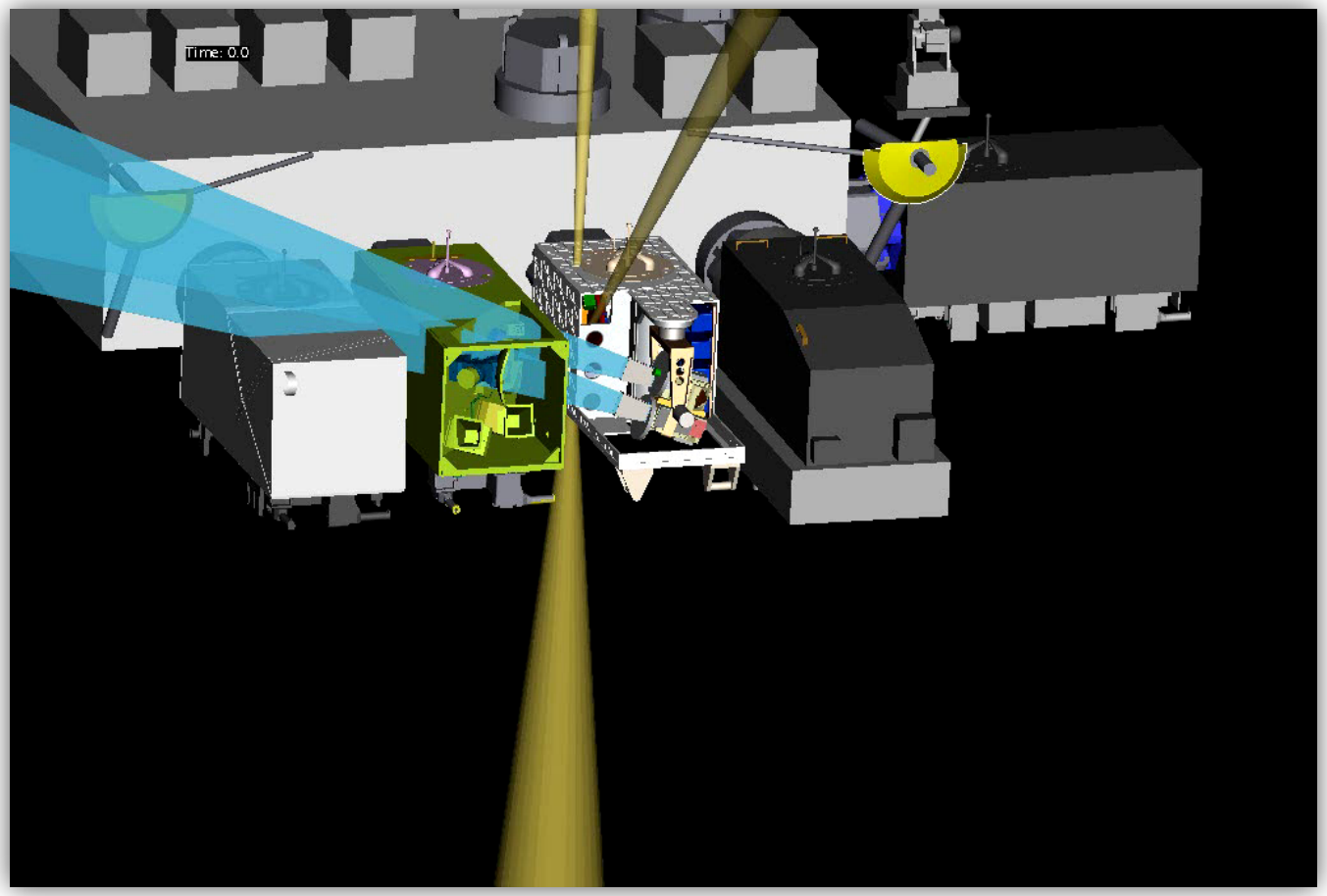
CLARREO ISS Concept Design 2013

	JEM-EF Site Capabilities	CLARREO-ISS Design Summary	
Mass	550 kg (standard site)	~453 kg with GFE (~20% margin)	☑
Power	3 kW (standard site)	~250 W (1100% margin)	☑
Thermal	3 kW (fluid cooling loop)	~250 W	☑
Data Rate	1 Mbps (MIL-STD-1553) 10 Mbps (10 Base-T Ethernet) 43 Mbps (Shared-Negotiated) NTSC Video	~640 kbps to ~72 Mbps (Highest rate due to RS during solar calibration requires data buffering at the payload)	☑
Data Volume	Negotiable – Up to 1.5 TB	~90 Gb/day	☑
Volume	0.8 x 1.0 x 1.85 m	Complies (stowed)	☑

Due to the ISS inclination orbit, CLARREO will not have coverage of Earth's polar regions, however, flying in a precessing orbit will significantly enhance sampling for inter-calibration of existing sensors.

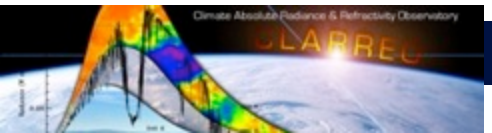
RS Benchmarking-Intercalibration Ops

CLARREO ISS Concept Design 2013



Preliminary studies show that the mass, power, volume, and thermal requirements are within a reasonable ISS design space.

Tech Demonstration Options (2014)

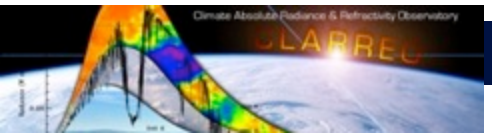


Background

- **SEWG Cross Mission Study (Spring 2013):** Seeking concept that could launch in the 2014-2018 time frame, Class D (or lower) instrument, commercial parts are acceptable, ISS provides interface hardware, launch costs and reserves not included in estimates. Costs in the $20M notional range.

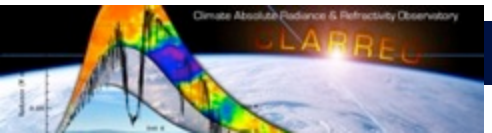
- **SDT Meeting at GSFC (1/8/14)**: The CLARREO team was asked to come up with options for a potential technology demonstration mission (Class D) on ISS (i.e., absolute calibration standard or engineering design unit).

- **Clarifying Questions posed by S. Volz…**
  1. What is the impact of a CLARREO technology demonstration(s)?
  2. What are the potential benefits/linkages to other missions, especially Landsat?
  3. Details on the projected technical margins, cost (with or without reserves), and schedule phasing for these technology demonstrations.
  4. What won't the technology demonstration do?



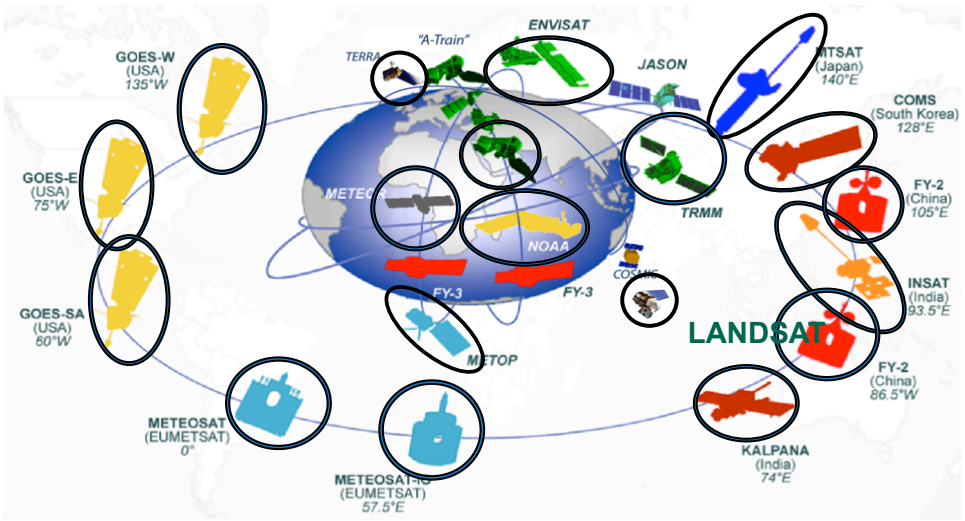
Q1- Near-Term Impact (<1 year)

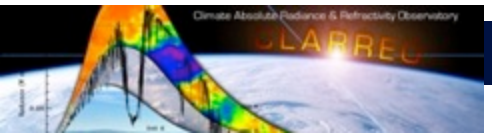
- During the 1st year of the technology demonstration, the following will be accomplished:
  - Flying on ISS will bring the UW and LASP instrument designs from TRL= 6 to 9
  - Demonstration of ***the first*** on-orbit SI traceable calibration methodologies to achieve accuracies 5 to 10x higher than current IR and RS instruments.
  - Demonstrate and test system in an operational environment. Identify any needed design modifications for full mission.
  - Provide ***first*** observed far-infrared (IR) spectra since Nimbus 4 IRIS in 1971 to enable studies of the Earth's water vapor greenhouse effect (50% in the far-IR), atmospheric cooling rate, and cirrus effects on the far-IR.
  - Provide a year of data on orbit crossings with NPP, JPSS1, METOP, Terra, Aqua, and geostationary satellites (5 for global coverage). Demonstrate the use of IR and RS as reference instruments for intercalibration as part of GSICS (Global Space Based Inter-Calibration System).
  - Put the lunar spectral irradiance on an SI traceable scale with 10 to 20 times the current accuracy of 5 to 10 % (1 sigma).



Q2- Benefits/Linkages to Other Missions

- Near term (<1 year):
  - Provide a year of data on orbit crossings with NPP, JPSS1, METOP, Terra, Aqua, and geostationary satellites (5 for global coverage). Demonstrate the use of IR and RS as reference instruments for intercalibration as part of GSICS (Global Space Based Inter-Calibration System).
  - Put the lunar spectral irradiance on an SI traceable scale with 10 to 20 times the current accuracy of 5 to 10 % (1 sigma).





Intercalibration of 30 to 40 instruments in LEO and GEO orbits

Q2- Benefits/Linkages to Landsat

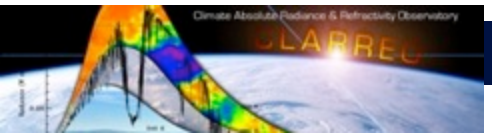
- CLARREO could potentially serve as a reference intercalibration standard for a constellation of lower cost, less capable Landsat imagers in two ways:

  1) direct comparison (full resolution data at SNO's, allowed time matching at nadir), the timing and frequency of these events will depend on the CLARREO orbit chosen: ISS, 90 degree polar or sun synch free flyer.

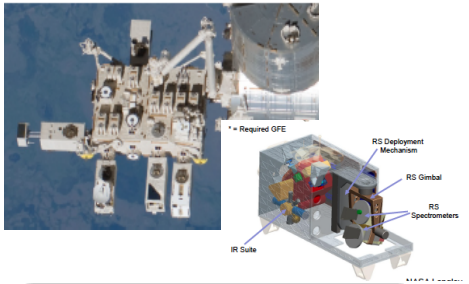
  2) vicarious intercal via characterized scenes (CEOS/GSICS catalogs of surface targets). CLARREO calibrates the surface targets. Less accurate than direct comparison but more frequent matches (atmospheric correction limits accuracy to about 1% (k=1)

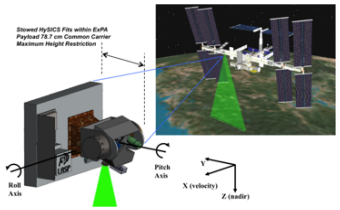
- Previous teams have performed vicarious intercalibration at ~3 - 5% (k=1) level. CLARREO should be able to perform intercalibration at the 1% (k=1) level and provide a single tie point for all land imagers to SI traceability.

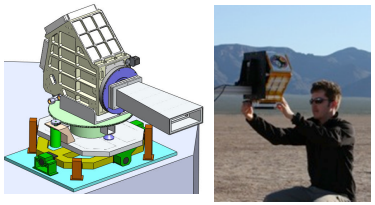
- Additional opportunities to intercalibrate with Sentinel 2A and 2B. They appear to have better spectral/spatial/repeat cycle capability than Landsat 8, with all Landsat bands, and similar calibration accuracy (<5%). Recent EU law mandating free and open data access policy for all Copernicus/Sentinel missions provides reliable community access to the data.

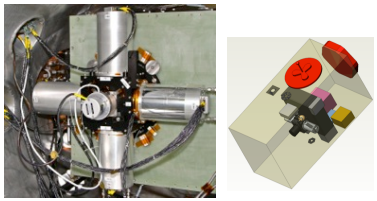


Q3 – Tech Demo Cost and Schedule Comparison









ISS Mission Concept (73% Science)	ISS Tech Demo LASP-Hysics, GSFC-Solaris, UW-Pathfinder (Tech Demo Level Science)		
2 instruments on ISS, RO is obtained from COSMIC-2 (LRD 2023) **Accommodated by JEM on ISS**	**1 instrument on ISS** **Accommodated by ELC on ISS**	**1 instrument on ISS** **Accommodated by JEM on ISS**	**1 instrument on ISS** **Accommodated by ELC, JEM, and Columbus Module on ISS**

Total Cost ~ $420M (Includes Reserves)

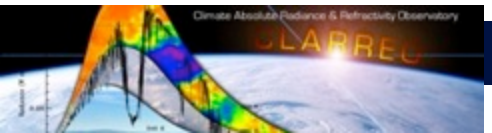
SEWG Initial Cost Target $20M (Range of inputs received from ~$25M to ~$55M)

Q4- What won't the Technology Demonstration do?

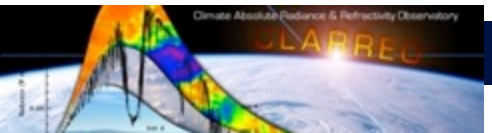
- A low-cost pathfinder on ISS should not be expected to achieve the full complement of scientific goals of a full CLARREO mission (conducted on one or more specialized free-flyer spacecraft), however, it can certainly be expected to achieve the risk-reduction goals mentioned prior and to demonstrate the full performance of the calibration and verification systems.

- Three areas for which the pathfinder would fall short of the full CLARREO mission are:
  (1) global coverage, due to the nature of the ISS orbit,
  (2) lifetime, due to the class D or lower approach to the mission, and
  (3) for IR nadir viewing, the ISS orbit conditions (e.g. attitude) would limit data collection to about 75% of total time on orbit.

- All of these limitations have the largest impact on achieving the highest accuracy science climate benchmark. However, there is much less impact on demonstrating extremely valuable technology development information related to the calibration and verification systems.



CLARREO Pathfinder – President's Budget Request (2015)



Budget Guidance & Guidelines

PPBE 17 ESD PRG Summary 02 11 2015 Rev 1

(NEW) CLARREO Pathfinder (564940)

Provide an in-guide budget submission to demonstrate essential measurement technologies of the CLARREO Tier 1 Decadal Survey mission. The submission should support the flight of two instruments, Reflected Solar (RS) and Infrared (IR) and spectrometers hosted on the International Space Station in FY 2019.

$K	FY16	FY17	FY18	FY19	FY20	FY21
CLARREO Pathfinder	$ 15,000	$ 14,800	$ 25,500	$ 7,500	$ 900	$ 200
HQ UFE	$ -	$ 2,500	$ 5,500	$ 5,000	$ -	$ -

Note:

- HQ Un-Funded Expenditures (UFE) is held by HQ and is generally unavailable to the project – i.e. CP cannot plan to use this as part of the budget or as reserves.
- ESD reserve posture requires that projects have 30% reserves. We will plan on 30% up to launch and then 10% reserves on Ops.

Planning Budget - Allocations

Fiscal Year	2016	2017	2018	2019	2020	2021	Totals
Major Milestones	MCR/SRR/ PDR	CDR+	AI&T	Launch	Ops	Ops	
PPBE Guidance ($K)	$15,000	$17,300	$31,000	$12,500	$900	$200	$76,900
HQ UFE	$0	$2,500	$5,500	$5,000	$0	$0	$13,000
CLARREO Pathfinder Available Funds	$15,000	$14,800	$25,500	$7,500	$900	$200	$63,900
30% Reserves	$3,465	$3,419	$5,891	$1,733	$90	$20	$14,761
Available Budget	$11,535	$11,381	$19,610	$5,768	$810	$180	$49,283

Note:

- The available budget must cover project management, systems engineering, S&MA, limited science, integration and test (leverage existing ground equipment), etc.
- Target of ~$20M per instrument.

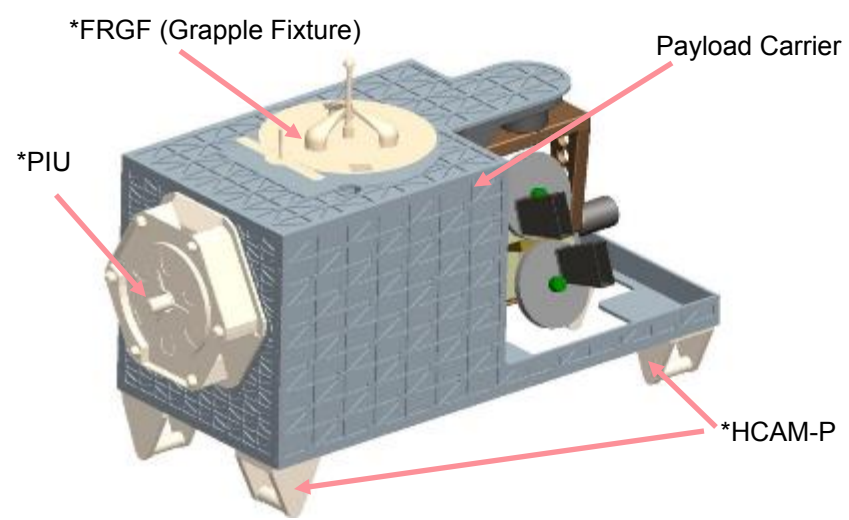
Planning Assumptions

- The objective of this pathfinder mission is to reduce risk and provide confidence that the full CLARREO could achieve the science goals. Focus on key elements for TRL advancement and avoid mission creep. This is not the CLARREO mission, rather it is a step towards the CLARREO mission.
- Project management approach must be lean and agile in order to maximize the funds to the Instruments.
- CLARREO Pre-Formulation budget will fund portions of the in-house workforce from the existing Calibration Demonstration System budget lines. Assumes work on existing CDS systems cease and the workforce redirected to the Pathfinder.
- Ops Concept TBD – Instruments may operate independently
- HQ Guidance
  - *Tailored Class D implementation approach*
  - *Science requirements can be adjusted to fit budget*
  - *Include both IR and RS instruments – keep options open at this early stage (Freilich).*
  - *ISS (Conover) will provide location and accommodation issues guidance*

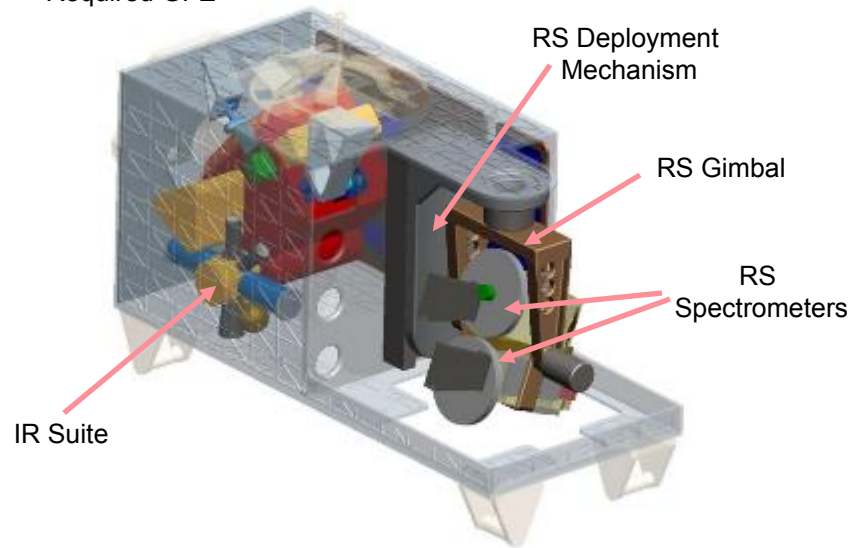
ISS Accommodations

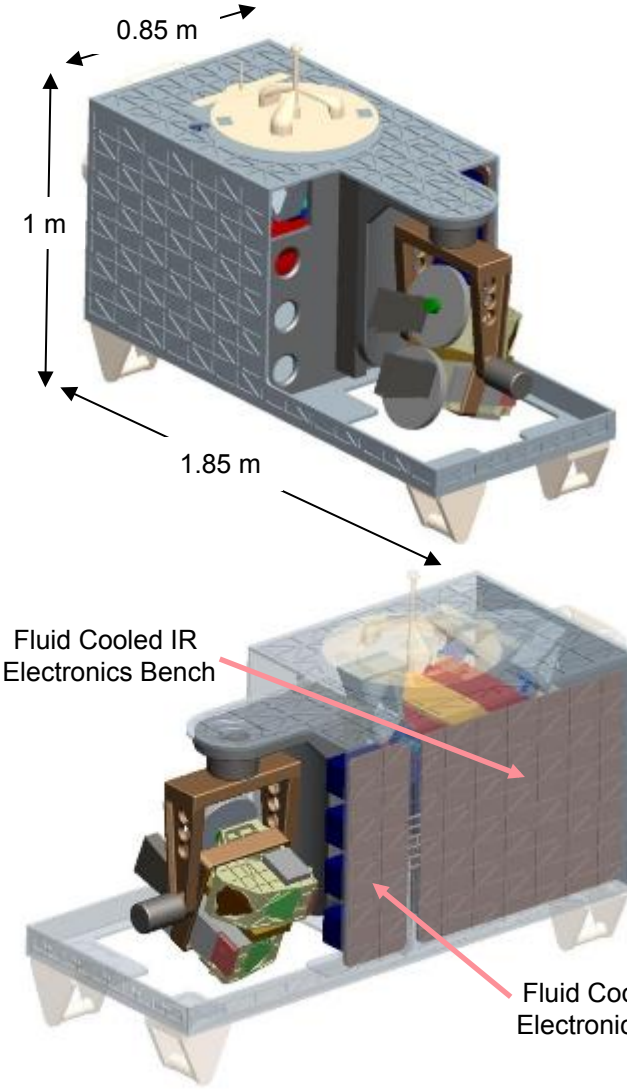
- **Assumptions:**
  - ISS provides payload adaptors/interface units, simulators, shipping to PI's institution, cost of access to space, ISS integration
  - Leverage existing hardware (e.g., SAGE-III IAM) where applicable to reduce costs
  - Launch to ISS on first available launch 4th Qtr. FY 19
  - A slot has not yet been selected on ISS, however, the ISS Research Office is fully aware of CLARREO Pathfinder. Next step – More detailed feasibility assessment.
  - Project start (funds available) 1st Qtr. FY 16
  - Independent calibration
  - Class D mode for instrument development and implementation
- **Issues/Challenges/Concerns:**
  - Acquisition approach (e.g., internal/external work) and timeline
  - Current life cycle schedule is success oriented.
    - Significant risk to schedule due to a Continuing Resolution that delays funding or a delay in funding approval.
  - Minimal de-scope options.
    - Most substantial de-scope is the deletion of one instrument

CLARREO-ISS Payload Concept Compatible with JEM-EF

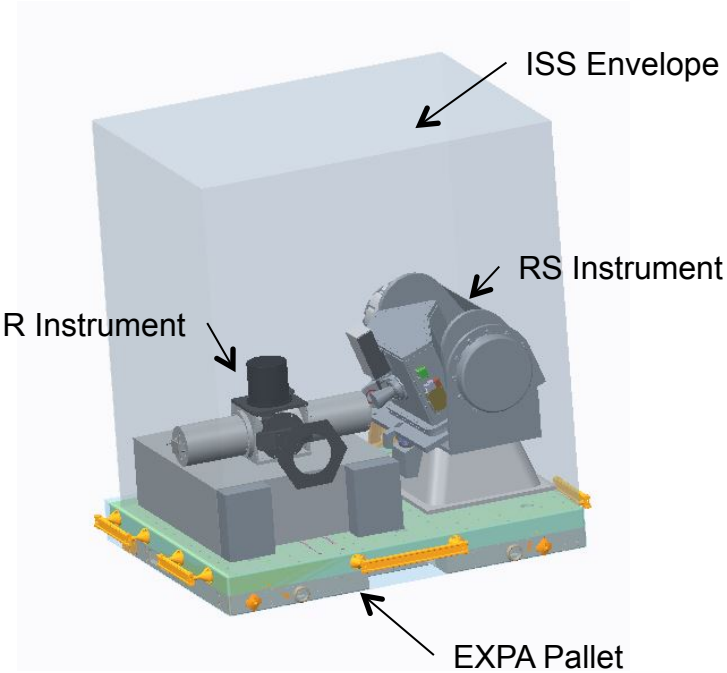


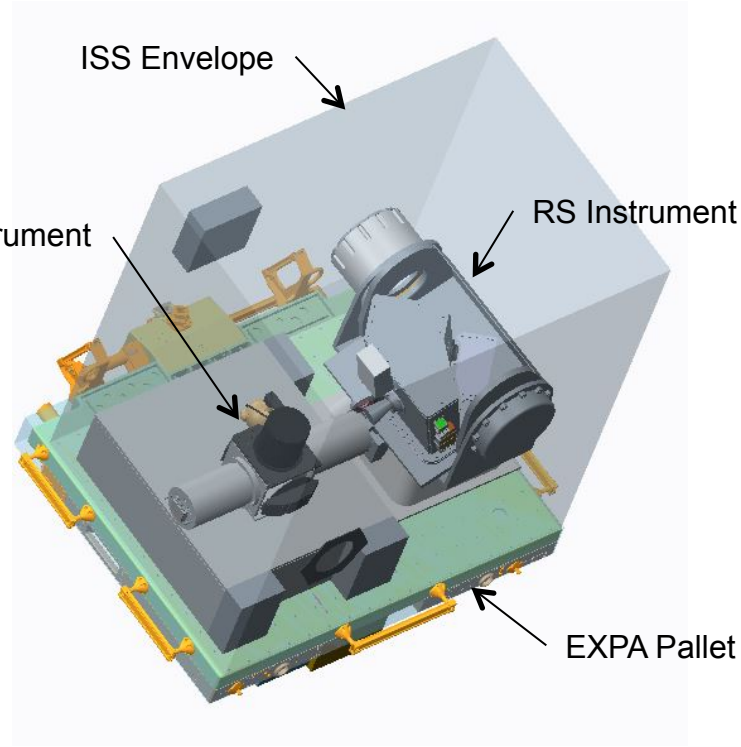
* = Required GFE





CLARREO-ISS Payload Concept Compatible with Express Logistics Carrier - ExPA Pallet





Next Steps

- Further clarification from HQ as to the ground rules
- Finalize approval of recommended Class D implementation approaches with Center management, ESMPO, and ESD. Leverage lessons learned from TCTE, STMD projects, Lightfoot memo, GSFC Class D Constitution document.
- Complete accommodation feasibility study for both instruments on the ELC.
  - Preliminary studies show that instruments can be accommodated. Work with K. Jules.
- RS and IR teams to plan to refine PPBE budget profiles – requirements will flow from what is achievable within the budget and schedule
- Procurement strategy discussions. Meeting recommended in May with Center management teams
- Formalize project team

- Backup

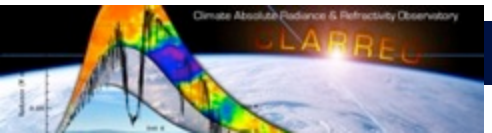
CLARREO Actionable Implementation Plan for Tailored Class D (NPR 7120.5E/7123.1B) (Proj/SE)

	CLARREO Class D Tailoring	Comments
Project Implementation Plan (PIP)	Control Plans included as Sections in PIP: Technical, Schedule, Cost & Resource Mngt, Proj Reporting, Acq., Tech Dev, SW Mngt, Rev Plan, Photo, Engr Sci & Data Mngt, Security, Exprot Ctrl, Termination Not Applicable: Tech Readiness Assmt Doc, Eng Dev Assmt Doc, Orbital Debris, End of Mission,	Per Lightfoot memo
Separate Control Documents	Fully Compliant: ISS Safety Requirements Tailored: SRD, SEMP, CMP, RMP, PAP, V&V Report, TOR, Mission Ops/Env Plan, AIT (Logist.),	Per Lightfoot memo
KDP	Center Level DA with appropriate HQ Mission Directorate participation, (Ctr Dir Chair)	KDP A-F at Center
Life-Cycle Reviews	IRT (in lieu of SRB) (FPD Chairs) follows TOR (Ctr/ESD sign) Fully Compliant: Peer Review (G19) Tailored: MCR, SRR, PDR, CDR, TRR, SAR, combined ORR/FRR Not Applicable: SIR, Post-Launch Assmt Rev, Critical Event Readiness Rev, Decommissioning Rev, Disposal Readiness Rev.	IRT (TA (CE, SMA), SMEs, SD, ED, RD, FPD etc), Same ITR for Instrument reviews, FPD is approving authority (Class D Champion), Informal reviews, with tailored entrance/exit criteria, directed feedback in lieu of RFAs, (FPD provides status to → Ctr Dir → ESMPO → ESD)
Reporting	The same Monthly CMC format/content is used to Center	CMC reports to Ctr Dir → ESMPO → ESD, reporting format is negotiated with Ctr DA
Management Approach	Tailored: Reserve (30% A-C, 10% D-E), Not Applicable: EVM / IBR, JCL Not Mandatory: CADRe Personnel: seasoned personnel for agile execution, continuity in lieu of rigorous process	Optionally submit CLARREO CADRe “lite” to NASA CADRe
Risk Posture	⬆Risk, ⬇Testing, ⬇Spares, ⬇Redundancy, ⬇ Space rated HW	Lower test levels & durations, fewer flight spares, single-string design with less redundancy, reduced QA (heritage), some non-space rated HW
Safety & Mission Assurance (TBD)	Do no harm and meeting the Class D Safety intent of NPRs (8720.1 - Reliability),(8730.5, 8735.1, 8735.2 - QA), (8705.5 Probabilistic Risk)	Same as Class D for all safety only. Tailored for non-safety related requirements.

Technical Credibility

- **Technology Maturity**: RS and IR Calibration Demonstration Breadboards developed and in test. Concurrent ESTO investments have successfully matured the required technologies to TRL=6.
- Next step - Proving that these technologies can work in their current form under mission conditions. A Tech Demo on ISS would be a major step in reducing the cost and technical risk for these high accuracy measurements.

- **Science Maturity** – The CLARREO SDT (in its 3rd year of operation) has provided expert guidance on measurement strategies, data quality, and high level data products and models that improve our understanding of long-term climate change.
- **Benefits of Tech Demo –** Demonstration of key technologies and initiation the climate record. Lowest cost option for obtaining a portion of CLARREO science.



EVM Status

- Recommendations for small Cat 3/Class D spaceflight projects under $150M (*R. Lightfoot Memo*) – If no development contract is projected to exceed $50M, then EVM system requirements shall not apply.

- EVM not applicable to CLARREO Pathfinder.

Project WBS Structure